Biomechanical simulation of the Charcot neuroarthropathic foot with plantar ulcer

Antoine Perrier, Nicolas Vuillerme, Vincent Luboz, Marek Bucki, Bruno Diot, Francis Cannard, Georges Ha Van, Yohan Payan

Biomechanical simulation of the Charcot neuroarthropathic foot with plantar ulcer.

A. Perrier[1,2,3,6], N. Vuillerme[3,4],V. Luboz[1], M. Bucki[2], B. Diot[5] ,F. Cannard[2], G. Havan[6], Y. Payan[1*]

[1*] UJF-Grenoble1/CNRS/TIMC-IMAG UMR 5525, Grenoble, F-38041, France, ypayan@imag.fr
[2] TexiSense, France, [3] UJF-Grenoble1/AGIM & [4] Institut Universitaire de France, France
[5] IDS, France, [6] Pitié-Salpetriere Teaching Hospital, France

Introduction

Diabetic patients with long-term diabetes are mainly affected by peripheral neuropathy. This lack of sensitivity induces a destructive process affecting joints and bony structures which can lead to the Charcot neuropathic osteoarthropathy (CNO). The CNO results in dramatic deformities and dysfunctional foot and ankle complex. For 15 to 43% of the patients, joints are damaged in the tarso-metatarsal zone leading to a mid-foot breakdown. This situation is described as type 2 CNO in Sanders classification [1]. The destruction and osteo-synthesis create deformities and cause luxations. The gait and stance are modified and overloads occur because of overpressures below the bony prominences. As the neuropathy makes the region insensitive to pain foot ulcers can appear. The principal suspected causes are excessive compression intensity (leading to internal strains above 50% for about 10 minutes) and duration (leading to internal strains above 20% for about two hours) [2]. Currently, there is no way to prevent foot ulcer resulting from the foot anatomy reconfiguration induced by CNO.

Methods

To explore this issue, a Type 2 CNO foot was reconstructed using the CT-Scan modality and the corresponding biomechanical finite element (FE) model was created. This model includes bones as rigid bodies and represents the soft tissues of the foot as two different sub-domains each modeled using a Neo Hookean material with Young moduli and Poisson ratios of 200 kPa and 0.495 for the skin, 40 kPa and 0.49 for the fat/muscles tissues. The sole of the foot model is put in contact with a virtual horizontal pedobarographic platform.

The Charcot patient was asked to perform a static standing acquisition of plantar pressures using a Zebris platform. The collected pressures were applied on the FE foot sole in order to compute internal strains. Then, the foot model including gravity and contact with the virtual pedobarographic platform was used to simulate a standing position. The corresponding sole pressure (SSPP: standing simulated plantar pressure) and internal strains thus computed can therefore be respectively compared with the measured standing plantar pressures (MSPP) and with the internal strains simulated from the MSPP boundary conditions.

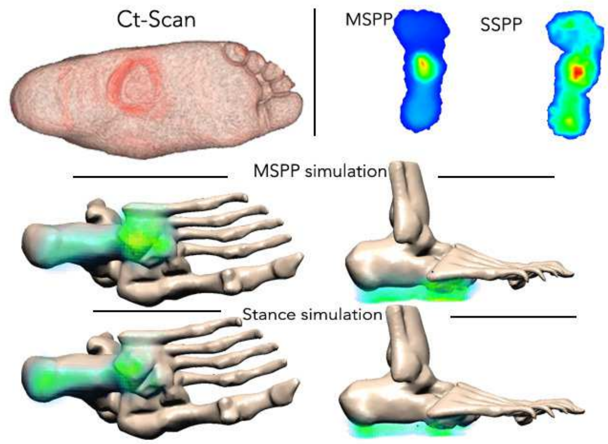
Results

The volumes and location of the largest clusters with contiguous nodes with Von Mises (VM) strains over 20% or 50% are similar (errors<5%) between measured pressure applied and static simulations. The simulated peak pressure value is also close to the one measured with the patient in weight bearing position. (Table 1) Fig 1.

Table 1: *Volume, in cm^3, of the largest cluster of nodes with a VM strain above 20% and 50%, the peak plantar pressure and their deviation in %.*

Conditions	MSPP	SSPP	Deviation
Mean cluster volume with strains over 20 % in mm^3	$1.92E^{-01}$	$1.84E^{-01}$	4.16%
Mean cluster volume with strains over 50 % in mm^3	$4.76E^{-02}$	$4.70E^{-02}$	1.26%
Peak Plantar pressure in N/cm^2	20	19.62	1.90%

Fig. 1: *Top: CT-Scan, MSPP and SSPP maps. Middle: MSPP applied: strains clusters. Low: Weight bearing simulation: strains clusters*



Discussion

The FE model of the type 2 CNO is able to predict, in weight bearing position, the location and the proportion of the Von Mises Strains in the soft tissue of the diabetic foot. The location is similar to the real plantar ulcer for this patient and the plantar pressure values are in accordance with the measurements. Indeed, a peak pressure value of 19.6N/cm^2 is simulated in regard of the cuboid bone, which happens to be the actual location of the ulcer.

Conflict of Interest

Some authors are involved with the TexiSense Company (http://www.texisense.com/home_en).

References
[1] Sanders L. et al. Diabetic neuropathic osteoarthropathy: the Charcot foot. The high risk foot in diabetes mellitus. 1991.
[2] Loerakker S. *et al.*, J. Tissue Viability. J. Appl. Phys., 111(4):1168-77, 2011.